Looking Back and Forward - Evacuation, Escape and Rescue (EER) from the Deepwater Horizon Rig

Jon Espen Skogdalen
Department of Industrial Economics, Risk Management and Planning
University of Stavanger, NO 4036 Stavanger, Norway
jon.e.skogdalen@uis.no
Phone/fax: +47 99 02 41 71

Jahon Khorsandi
Center for Catastrophic Risk Management
University of California, Berkeley
jahonk@berkeley.edu

Jan Erik Vinnem
Department of Industrial Economics, Risk Management and Planning
University of Stavanger, NO 4036 Stavanger, Norway
jev@preventor.no

Abstract

Escape, Evacuation, and Rescue (EER) operations played a vital role safeguarding the crewmembers' lives on the night of the April 20th blowout on board the Deepwater Horizon. No casualties were reported as a result of the EER operations. 115 of the 126 members on board were evacuated or rescued. The number of survivors from the Deepwater Horizon offers a limited insight into the level of success of the evacuation, escape and rescue (EER) effort. Several of the safety barriers elements that are critical for EER operations failed during the Deepwater Horizon accident. The high number of survivors is due to fortunate circumstances, including good weather conditions, lifeboats being filled before lowered and the effort of the supply ship Damon Bankston. Testimonies have revealed that several of the safety critical systems on Deepwater Horizon failed partly or totally. These systems included BOP, ESD, alarm system and power generation More research is needed to reveal the reliability and operation of the safety critical systems. As seen in the case of Deepwater Horizon is there a need for secondary evacuation measures. These measures can in addition to life rafts be escape chutes and ladders. Personal survival suits with splash protection extend rescue time and increase protection from waves and hydrocarbons in sea, in addition to extend time before hypothermia. The life raft should include emergency beacon. During a crisis, it is possible that situations will occur where bypassing the chain of command is unavoidable and necessary; however, the situation must be properly assessed by the individuals such that the result is not detrimental to the safety and success of the operations. This can be accomplished through proper training, and the implementation and practice of worst case scenarios as a part of training and drills. To determine which measures would reduce the time taken to make decisions, and which steps would lead to people choosing the right escape routes, we need information about the perceptions, intentions and motives of those who are trying to evacuate and escape from the hazardous situation. There is a need to analyze the system for rescue of personnel in sea, life rafts and life boats. The system should include the rig owner, industry partners in area and UCGS. The capability to quickly and efficiently rescue personnel at all times should be analyzed.

Keywords: Evacuation, escape, rescue, Deepwater Horizon

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Abbreviations

BOP	Blow-Out Preventer
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
DPO	Dynamic Positioning Operator
EEP	Elevated Exposure Phases
EER	Evacuation, Escape and Rescue
FRC	Fast Rescue Craft
PA	Public address
POB	Personnel Onboard
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
TSR	Temporary Safe Rescue
USCG	United States Coast Guard

1 Introduction

Escape, Evacuation, and Rescue (EER) operations played a vital role in safeguarding the crewmembers' lives on the night of the April 20th 2010 when a blowout occurred on board the Deepwater Horizon offshore drilling rig, located in the Gulf of Mexico. Eleven workers were killed in the explosion. However no casualties were reported as a result of the EER operations. 115 of the 126 members on board were evacuated; 107 workers evacuated using the lifeboats, 3 used a life raft, and 5 jumped directly into the sea[1]. Two days later, the Deepwater Horizon rig sank [1]. The results of the evacuation from the Deepwater Horizon must not be taken for granted. There are many risks associated with the evacuation of personnel from offshore installations in the case of an emergency, and the examples below further emphasize this matter.

In 1980, 123 people were killed when the Alexander Kielland platform collapsed and sank in the Norwegian sector of the North Sea. A fatigue crack in one of the legs caused the floating hotel to collapse and capsize. Lifeboats were smashed against the rig's legs, causing them to break. Many of the men were swept away. Only 89 of the 212 men onboard survived [2].

In 1982 the Ocean Ranger semisubmersible capsized and sank on the Grand Banks of Newfoundland during a severe winter storm packing 90-knot winds and high seas. The Royal Commission on the Ocean Ranger Marine Disaster indicated that a huge wave had swept over the rig, breaking a porthole in the ballast control room, shorting circuits, and causing the rig to list. All 84 crew members died, at least some of which during or following attempts to transfer survivors from the lifeboat to a vessel without rescue facilities [3].

In 1988, a massive gas condensate leak resulted in an explosion and fire on board the Piper Alpha production platform in the North Sea, killing 167 workers and leaving only 59 survivors, resulting in one of the worst offshore accidents ever. Many crewmembers lost their lives because they were not able to successfully evacuate the installation [4].

A more recent example is the Usumacinta accident on October 23rd, 2007, where 22 people died after launching the lifeboats and abandoning the mobile drilling unit. Various decisions such as opening the hatches or prematurely abandoning the lifeboats resulted in the death of the crew [3].

When a major hazard occurs on an installation, evacuation operations can play a vital role in safeguarding the lives of personnel by safely removing them from the danger zone. However, as shown in some of the examples above, evacuation operations can have tragic outcomes, and although such accidents have had major impacts on legislation, training, and operating procedures, the risks pertaining to such operations continue to exist.

1.1 Objective

In this working paper, the EER operations from the Deepwater Horizon installation are reviewed based on testimonies provided by the crewmembers during the Joint Investigation by the Unites States Coast Guard, and the Bureau of Ocean Energy Management [5]. The objective is to analyze the various hazards and success factors pertaining to the EER operations, and to suggest possible improvements based on the findings.

This working paper includes an analysis of the sequence of events from when the blowout was detected, until the crew was outside the platform safety zone (500 m) and thereby judged to be in safe distance hazards caused by the rig.

The possible failures of safety critical systems (and barriers) including the fire and gas alarm system, alarm system, the blowout preventer (BOP), and the emergency disconnect system (EDS) are not analyzed. For more details on the reliability and testing of these systems see [6]. It is important to note however, that the performance of these safety critical systems influence EER operations.

[1] The numbers are based on testimonies, interviews and newspaperarticles, and is thereby not official.

The terms "evacuation", "escape" and "rescue" are defined in paragraph 20.2 of the Cullen Report on the Piper Alpha Disaster Inquiry [7], as follows;

- Evacuation refers to the planned method of leaving the installation without directly entering the sea. Successful evacuation results in those on board the installation being transferred to an onshore location or to a safe offshore location or vessel.
- Escape refers to the process of leaving an offshore installation in the event of part or all the evacuation systems failing, whereby personnel on board make their way into the sea by various means or by jumping.
- Rescue refers to the process by which escapes and man overboard (MOB) casualties are retrieved to a safe place where medical assistance is available.

1.2 Hazards

Some of the hazards which can potentially lead to EER are [8, 9]:

- Blowouts, including shallow gas and reservoir zones, unignited and ignited
- Process leaks, unignited and ignited
- Utility areas and systems fires and explosions
- Fire in accommodation areas
- Helicopter crash on platform
- Collisions, including fields related traffic, and external traffic, drifting and under power
- Riser and pipeline accidents
- Accidents from subsea production systems
- Structural collapse, including collapse of bridges between fixed and/or floating installations
- Foundation failure
- Loss of stability/position
- Extreme weather

The hazards that crew can exposed to during EER can be divided into three categories [10]:

• Physical	Physical hazards are those due to equipment (design, malfunction or failure) and physical conditions (environmental, fire, smoke etc.).
• Command and control	Command and control hazards are those due to poor procedures, inadequate communications and breakdown of safety management systems, examination of operations manuals and from the human errors/failures analysis.
• Behavioral	Behavioral hazards are those due to human error or failures as well as undesirable behavior. These hazards were identified using the human errors

1.3 Success factors for EER

The main factors which can lead to the success of EER from offshore installations can be summarized as [10]:

- Hazard prevention, control and mitigation
- Appropriate installation physical design (e.g. escape routes, muster area)

- The performance of equipment in an emergency (e.g. alarm systems, fire-fighting equipment, helicopters, TEMPSC[2], FRCs[3])
- The action of the personnel concerned (e.g. offshore emergency response teams and general POB), often summarized as human and organizational factors

Human error and human factors are often used interchangeably, thus creating confusion and compromising the quality of human reliability assessments [11]. Therefore, defining human factors and human error is necessary to establish a basis for the discussion in the current paper. A definition of human factors, modified slightly from the UK's Health and Safety Executive [12], is as follows: Environmental and organizational and job factors, system design, task attributes and human characteristics that influence behavior and affect health and safety.

'Human factors' are a range of issues including the perceptual, physical and mental capabilities of people and the interactions of individuals with their job and the working environments, the influence of equipment and system design on human performance, and above all, the organizational characteristics which influence safety related behavior at work. There are three areas of influence on people at work, namely: (a) the organization, (b) the job, and (c) personal factors. These are directly affected by: (a) the system for communication within the organization, and (b) the training systems and procedures in operation—all of which are directed at preventing human error [13].

1.4 Legislation

In the U.S., The U.S. Coast Guard (USCG) regulates the safety of life and property on the Outer Continental Shelf (OCS) facilities and vessels engaged in OCS activities, and the safety of navigation. In addition, the USCG is responsible for promoting workplace safety and health by enforcing requirements related to personnel, workplace activities, and conditions and equipment on the OCS [14].

USCG regulations 33 CFR Subpart N – Outer Continental Shelf Activities are applicable and are "intended to promote safety of life and property on OCS facilities, vessels, and other units engaged in OCS activities, protect the marine environment," Sub-parts B (Manned OCS facilities) and C (Mobile Offshore Drilling Units) in 33 CFR 146 are relevant to drilling and well activities. Both subparts have requirements for operators to develop and submit approval Emergency Evacuation Plans (EEP) to the USCG. The EEP submissions must include, amongst other requirements:

- A description of the recognized circumstances, such as fires or blowouts, and environmental conditions, such as approaching hurricanes or ice floes, in which the facility or its personnel would be placed in jeopardy and a mass evacuation of the facility's personnel would be recommended
- For each of the circumstances and conditions described a list the pre-evacuation steps for securing operations, whether drilling or production, including the time estimates for completion and the personnel required
- For each of the circumstances and conditions described a description of the order in which personnel would be evacuated, the transportation resources to be used in the evacuation, the operational limitations for each mode of transportation specified, and the time and distance factors for initiating the evacuation
- For each of the circumstances and conditions described, identification of the means and procedures for retrieving and transferring personnel during emergency situations and the ultimate evacuation of all personnel

[2] Totally Enclosed Motor Propelled Survival Craft
[3] Fast Rescue Craft

1.5 Evacuation Sequence

The following figure shows the different steps pertaining to an evacuation from an offshore installation – from the initiating incident, through the abandonment of the vessel. In the case of Deepwater Horizon, this refers to when the blowout was first recognized, to when lifeboats have abandoned the platform zone (500 m).

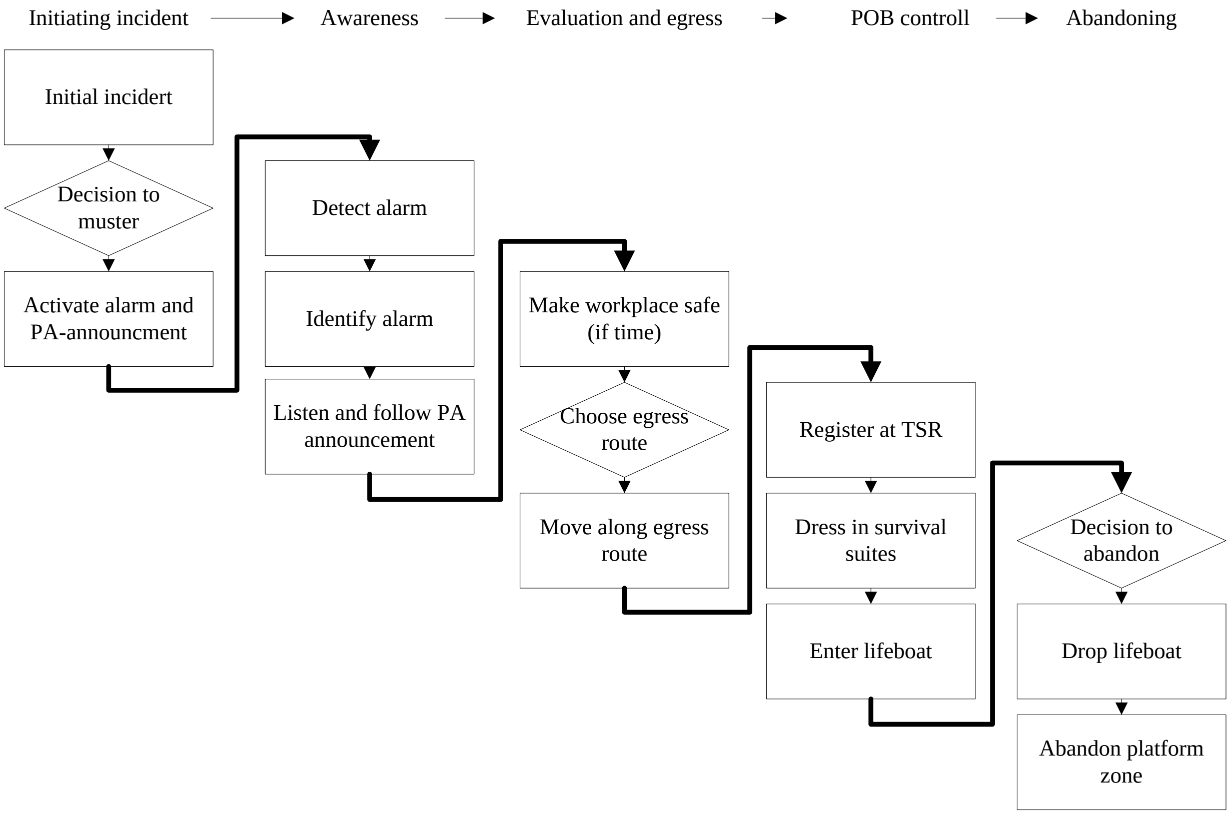

Figure 1.1 – The evacuation sequence

Figure 1.1 includes the steps of an evacuation process, but does not include the means of escape. The term evacuation refers to the process of leaving the installation and its vicinity in a systematic manner, and without directly entering the sea. Escape devices may cause people to enter the sea with little or no protection, and therefore the likelihood of survival is lower than that for evacuation systems.

2 EER from the Deepwater Horizon

Evacuation from the Deepwater Horizon began within minutes after the blowout and subsequent explosions on board the rig. It is impossible to know exactly what happened during the crisis on the night of April the 20, 2010, however, based on the various accounts and testimonies of crew members, an overall sequence of events, including various hazards associated with those events has been outlined. It is important to note that the information provided is based on an interpretation of limited information as provided by the testimonies during the Deepwater Horizon Joint Investigation [5].

2.1 Initiating incident

At approximately 9:45 pm, a blowout and subsequent explosions and fire erupted on the rig. The sequence of events leading to the blowout and explosions has been examined in detail in The National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling Meeting 5, [15].

2.2 Awareness

The sudden occurrence and impact of the explosion made it difficult for members on the bridge to assess the situation immediately following the incident. Also, various alarms were sounding and lights were flashing, making it difficult for the crew to acknowledge what was going on. The Senior DPO who was located on the bridge at the time of the incident recalls the scene as follows: [October 5, 2010 [5]]:

	"… they[alarms] were going off like crazy, so we were trying to find where these alarms were actually coming from.
Question:	*So the alarms went off and you silenced them to try and respond to what the casualties were; is that the way that worked?*
Answer:	*Yeah. But every time you silence those -- At that point in time, it did no use to silence an alarm, because there were some alarms that were just one on top of each other. It was just going crazy………."*

Another of the DPO officers on the bridge that evening also recalls the scene on the bridge as follows [October 5, 2010 [5]]:

Question:	*…why didn't you signal immediately the general alarm when two of the sensors came up magenta on the combustible gas alarms?*
Answer:	*It was a lot to take in. There was a lot going on. And soon after, I went over and hit the alarms.*
Question:	*But you didn't do it immediately, correct?*
Answer:	*No, sir.*
Question:	*And, in fact, at the time there were, by your testimony, more than ten to 20 magenta combustible gas alarms going off?*
Answer:	*Correct.*
Question:	*And did you consider at any time initiating an emergency shutdown of any ventilation aboard the rig?*
Answer:	*No, sir.*

Question:	*Did anyone discuss it [ESD]? Did you hear anyone discussing it on the bridge at that time?*
Answer:	*Not that I remember.*
Question:	*It was not an option put forth at any period of time that you were on the bridge following the jolt?*
Answer:	*No. Not that I remember.*

Question:	*Did anyone tell you after the first explosion that the situation was under control?*
Answer:	*Yeah, I did hear someone say that. That was probably said to calm people down.*
Question:	*Do you recall who said that?*
Answer:	*The captain.*

Transocean employees testified that the Deepwater Horizon's general alarm systems were inhibited prior to the explosion to avoid waking crewmembers in the middle of the night due to false alarms. [July 23, 2020; August 23, 2010][5]]. According to the Chief Electronics Technician, inhibited alarms mean that the sensors continue to detect hazards and forward the information to the computer; however the computer will not automatically trigger the alarm upon detecting a hazard. [July 23, 2010[5]]. This implies that the on the Deepwater Horizon, the general alarm system designated to notify the crew in the event of a fire required manual activation by a member on the bridge. In turn, several crew members on the rig floor and those closer to the location of the explosion had become aware of the severity of the incident before the general alarms were sounded.

In addition, it has been testified that the general alarm did not sound prior to the first explosion on the platform [October 5, 2010; July 23, 2010 [5]]. Traditionally, mustering would occur once the alarms were sounded, and the decision to muster is announced on the PA system. However, as noted in the testimony below[August 24, 2010 [5]], some crewmembers recall that they did not see or hear any alarms after the explosion. As a result, they had begun evacuating the rig as soon as they witnessed and experienced the shear impact of the blowout.

Question:	*"Do you recall the order of the alarms on the bridge when the incident occurred, what alarms sounded and in what order?*
Answer:	*We received the alarms from the fire and gas after the first explosion.*
Question:	*… Did you ever see any sort of visible alarms on that rig once you heard the loud noise you heard and started experiencing the things with the rig that you experienced, did you see any visual alarms anywhere on the rig of any type?*
Answer:	*Not from the -- the place I was at on the boat deck or in the short distance through the hallways in the accommodations did I see any visual alarms, nor did I hear any."*

2.3 Evaluation and Egress

Egress routes are the routes crewmembers use to escape from their current workplace or location and arrive to the designated muster stations on board the vessel. These routes are pre-planned, and provide the safest means of escaping a hazardous area. As the crew was making their way to the muster stations, many of the egress routes and stairways were blocked or impaired [May 27, 2010 [5]].

According to the Chief Electronics Technician on board the Deepwater Horizon, egress routes were severely impaired as a result of the explosions. His accounts of the events are as follows: [July 23, 2010[5]]:

"That [first] explosion blew the fire door that was between me and those spaces off the hinges."

"…as I reached the next door, I reached up and grabbed the handle for it. It then exploded. That was Explosion Number 2."

"…I remember getting really angry. I don't know why I got angry. I was mad at the doors. The doors were -- They were beating me to death. Two doors in a row had hit me right in the forehead and, you know, planted me against the wall somewhere. My arm wouldn't work, my left leg wouldn't work, I couldn't -- I couldn't breathe, I couldn't see."

"All the panels for the flooring were missing. There was nothing but grid work. So I was tripping and falling kind of through this grid work, trying to make my way to the outside water-tight door."

"So I turned to the right, and as I did, I got my bearings, got my eyes cleaned out enough where I could see, and noticed there was no walkway, there were no handrails, and there was no stairwell left. One more step and I would have went in the water. At that point I looked up at the wall, and the exhaust stacks for

Engine Number 3, the wall, the handrail, the walkway, all those things were missing. They were completely blown off the back of the rig."

Flames and impaired egress routes had cut off access to the aft lifeboats for some of the crew, rerouting them to their secondary muster stations.

The Senior Tool Pusher describes the wreckage in the living quarters as a result of the explosion: [May 28, 2010[5]]:

"…we had to remove debris. It was hanging from the ceiling and the walls was jutted out, the floor was jutted up. I mean it was just total chaos in that area of the living quarters."

2.4 Personnel On Board (POB) Control

Typically as part of the evacuation procedure, once crewmembers reach the designated muster stations, they register their names so that a proper head count can be conducted and missing members can be accounted for. Based on the testimonies provided, there were efforts to prepare such a headcount, however there were difficulties when trying to accurately account for all members. In his testimony, the Crane Operator describes his account of the events, and the difficulties in obtaining a proper headcount [May 29, 2010 [5]]:

"We was still trying to get people on the boat and trying to calm them down enough to -- trying to calm them down enough to get everybody on the boat. And there was people jumping off the side. We was trying to get a count and just couldn't get an accurate count because people were just jumping off the boat…"

"And we were trying to get people to count "1, 2, 3" around the boat trying to see how many we had in there and people couldn't even count right because they was too scared. So, what we done is we just went ahead and filled the boats up to their max and loaded the wounded we got on there and then lowered the boat…"

The Chief Mechanic describes the situation [May, 16, 2010 [5]]

"Upon entering the bridge, it was complete chaos. They were trying to get systems going, they were trying to get control back, and I asked the captain, 'We're here, Mike ….. has an injury.' So he told us to go to the lifeboats and find the medic. We proceeded to the lifeboats, whereupon I lost track of Mike. And so I went to my lifeboat that I was stationed to go to. And we waited around outside the lifeboat, waiting to receive orders. And it was just complete mayhem, chaos, people were scared, they were crying."

The Operations Manager describes [Aug 23, 2010 [5]]:

And I heard somebody yelling in the background that they're jumping overboard. So I ran back down the stairs. And in between the two life boats, on the outside of the handrail, there was an individual hanging on the outside of the handrail, and I said, "Hey, where you going? There's a perfectly good boat here. Do you trust me?"

The Subsea Engineer describes [July 22, 2010 [5]].

"It was a raging fire, it was out of control. There was a sense of urgency, we needed to go. And people were frozen up, they couldn't move. And I saw a couple of people jump off the side. I grabbed people and asked them if they checked in. I told them to get into the lifeboat and, you know, did that for a few people. People started going. I got in the lifeboat myself and everybody filled in, closed the doors, we deployed the life vessel"

2.5 Abandoning

While crew members on the bridge were trying to assess the situation, others were already mustering near the lifeboats. Some were urging for the lifeboats to be launched despite them being only partially full [5]. Deepwater Horizon did have a split command depending on what was the status of the rig; latched up, underway or in an emergency situation.

The decision to evacuate the rig rested upon the Captain when the rig is in an emergency situation, but from the testimonies it seems to be unclear who was in charge due to missing procedures of handover and interpretation if the rig was latched up, underway or in an emergency situation.

In his testimony during the joint investigation by the United States Coast Guard and the Bureau of Ocean Energy Management, the crane operator described the scene as follows [14 – May 29, 2010]

> *"…it was a lot of screaming, just a lot of screaming, a lot of hollering, a lot of scared people, including me, was scared. And trying to get people on the boats. It was a very unorganized – we had some wounded we was putting in the boat. Had people on the boat yelling "Drop the boat, drop the boat" and we still didn't have everybody on the boat yet. We was still trying to get people on the boat and trying to calm them down enough to -- trying to calm them down enough to get everybody on the boat. And there was people jumping off the side."*

One of the crew members jumped to the sea, and recall the situation [May 28, 2010 [5]]:

Question:	*[...] if you had been through all those drills and you had confidence that you thought basically the folks knew what they were doing, what was it that basically made you decide to go one deck down and jump? Were you frustrated, were you, you know, overly concerned? Was it getting hot? I'm just really kind of curious.*
Answer:	*It was a decision that I made because I didn't think we had time to wait.*
Question:	*You thought it was taking too long to get the boat out?*
Answer:	*I just -- they had a series of explosions, it's time to go. That was my thought process.*
Question:	*Can you estimate for us from the time that you heard the first explosion, you went to the boat deck, before you made your decision to go down and jump how much time elapsed?*
Answer:	*Fifteen minutes maybe.*
Question:	*And, when you were on that fast rescue boat, did they retrieve other people from the water or did they rescue you and take you back over?*
Question:	*Okay.*
Answer:	*There were four guys that had jumped.*

It seems unclear as to when exactly the decision to abandon was made and by whom., however in his testimony during the joint investigation by the USCG and the BOEM, a senior Transocean employee visiting the rig at the time of the incident, described how he instructed the lifeboats to depart [August 23, 2010 [5]]:

> *"…looking up at the derrick, you can see the derrick, and everything was ablaze there, and there was some individuals yelling, 'We've got to go. We've got to go. We've got to go.' And I said, 'We've got plenty of time.' And right about that time is when the traveling equipment, the drilling blocks and whatnot on the derrick fell. They were probably 40 to 50 foot in the air, you know, weigh 150,000 pounds, and they didn't make any noise. So at that time, I instructed the boat to my right, which would have been the port survival boat, to depart. They did. "*

Question:	*If you were not in command, why would the life boat coxswain lower his boat based on your communication and evacuate away from the Deepwater Horizon?*
Answer:	*I only know that when we left the bridge that we were going to abandon the vessel.*
Question:	*If you weren't in management-performance, would the coxswain take your word and leave and lower the boat and release?*
Answer:	*I don't know why he would take orders from me. I'm not the master of the vessel. But he did."*

The crew eventually launched the lifeboats, leaving some members behind. The following is an excerpt of the testimony of the subsea supervisor for the Deepwater Horizon: [14 – August 25, 2010][5]]:

Question:	*So what was the atmosphere like inside the lifeboats?*
Answer:	*It was a little hectic.*
Question:	*A lot of yelling and things like that?*
Answer:	*Yes. A lot of people was wanting to lower the boat before we got all the people in it.*
Question:	*So by the time you got -- the boat was lowered, there was still enough room inside the lifeboat, sir?*
Answer:	*Yes.*

The Senior DP officer who was located on the bridge at the time of the incident signaled for help from the nearby supply ship, the Damon Bankston, which in response launched a Fast Rescue Craft (FRC) to help rescue those at sea. Two lifeboats were launched from the Deepwater Horizon, and the crew made their way to the Damon Bankston. Some of the members who were left behind on the rig used a life raft to evacuate. However after the raft was lowered to sea, the remaining crew members on the rig, who were left behind by both the lifeboats and life raft, jumped to the sea. The Chief Engineer, who was in the life raft below the rig, describes the scene as he witnessed members who had jumped [July 19, 2010 [5]]:

> *"I saw a person's boots and his clothing and stuff come shooting through the smoke. Just before he landed, ……..He landed approximately five feet from me. Within seconds, a half a second later, another pair of boots and person came flying out of the smoke and he was approximately ten feet from me. Just before he hit the water, …... As we're swimming, trying to pull this life raft away from the rig, I got to a point where I could see the helideck. I witnessed an individual running at full speed across the helideck. When he jumped off the end of the helideck, he was still running. Just before he splashed into the water, he was actually looking over at us ….."*

The crew that had launched the life raft faced various challenges in their attempt to evacuate and escape the vicinity of the burning rig. The following excerpts are from the testimony of the rig's Chief Engineer,who was one of the crewmembers who evacuated using the life raft [July 19, 2010 [5]]:

> *"All the flames and heat from the rig floor were coming down the forward part of that deck, as well as all of the flames and the heat from under the rig. They were meeting, I guess, in like a vortex or something right there at the life raft."*
>
> *"At that point, I honestly thought that we were going to cook right there. The life raft, I guess from hurriedness and jumping in there and so forth, it actually fell. At that point, the life raft actually dipped forward and back. It started rocking back and forth. There was smoke in the life"*
>
> *"…I noticed that shortly after that, that we were not going any further from the rig. About that time, somebody hollered out, 'Oh, my God, the painter line is tied to the rig.' I looked back over my shoulder past the life raft and noticed the white painter line going up into the smoke. At that point, I heard ….., which was right behind me, started screaming for help, 'Help. We need help over here.' I looked out to see and I would have to say probably 50, 60 yards away there was the fast rescue craft, the FRC, from the Dameon Bankston. I saw two flashing lights in the water. Just as I looked at it, one of those was getting hauled into the boat and seconds later, the second person was hauled into that boat. The fast rescue craft started driving towards us and we were hollering, 'We need a knife. We need a knife.' When they got probably ten or 15 feet from us, an individual came up to the bow of the boat with a very large, foldable pocket knife. Curt swam out, grabbed the knife and swam to the back of the life raft. I followed Curt to the back of the life raft to assist if he needed it. He cut the rope."*

Within minutes, the rescue craft which had been launched by the crew of the Damon Bankston was able to rescue the crewmembers from the water and make its way to the life raft tied to the rig, cut the line, and tow it to safety.

One of the crew members who had helped lower the life raft, but was left behind on the rig describes how he made his decision to jump [October 5, 2010 [5]]:

Question:	*Other than jumping from the rig at that point, were there any other alternatives to evacuate the rig?*
Answer:	*Yeah. I mean, if I wanted to sit there and crank up the life raft davit, crank the hook back up and hook up another one. In a situation like this, you never know how much time you got, so I did, you know, the best thing I thought.*
Question:	*I'm certainly not criticizing your decision to jump. I'm just looking at alternative evacuation methods. Were there ladders that would go down to the water's edge?*
Answer:	*There was a ladder that was right there, but those ladders were severely damaged due to running from hurricanes, that you would have to jump from them anyway.*
Question:	*So my understanding from what you said is there were ladders designed, but the ladders had suffered damage, so they were not functional; is that correct?*
Answer:	*Those ladders were designed -- I don't know if they were designed for an emergency escape route, but I know they were used during the shipyard for people to get up to the rig. I don't know if they were emergency use.*
Question:	*Do you know if the ladders could have been used to go from the deck to the water?*
Answer:	*They could have, but like I stated earlier, the bottom 15, 20 feet was so severely damaged from waves that you still would have had to jump.*

Another hazard facing those who had jumped to sea was the presence of oil and other possible toxic and flammable material which had covered the surface of the water following the explosion. One of the final remaining crewmembers on board the Deepwater Horizon, describes the problems he faced once he had jumped in to the sea [July 23, 2010 [5]]:

> *"Once I hit the water, when I came back up, I couldn't see anything again because now I've got a new set of problems. I've got oil, hydraulic fluid, gasoline, diesel, whatever it is that's floating on the water is now burning my entire body. I'm now covered in this sludge. I don't know what it is. It's burning, I can't hardly breathe, but I can feel the heat from the fire underneath the vessel. At that point I started back stroking with the one arm and one leg that would work until I remember feeling no pain, I remember feeling no heat and thinking that that was it, I had died."*

The Damon Bankston played a critical role in rescuing and providing a safe-haven to personnel who had abandoned the Deepwater Horizon. The fast rescue craft (FRC) launched by the Bankston not only rescued crewmembers from the water; it also rescued the life raft which had been unexpectedly tied to the rig. The rescued crew received medical attention on board the Damon Bankston, and the seriously injured were airlifted and evacuated by the USCG from the deck of the Bankston.

The following is an excerpt from the testimony of the Chief of incident response for the United States Coast Guard's (USCG) 8th District [October 4, 2010 [5]]:

Question:	*Are you aware of any unique challenges they [USCG] face in deepwater emergency response?*
Answer:	*Oh, yes, a number. I mean, it is a fairly confined area. There is nowhere to go other than the water. And also, to get assets there, floating assets there, it takes quite a while. Roughly, you know, for -- just for the Deeepwater Horizon, we are looking at about 12 hours to get patrol boats on the scene.*
Question:	*Specifically, how do you plan to rescue 126 personnel with, I believe you said, 11 helos in the Gulf of Mexico, in an evacuation similar to this if there was no DAMON BANKSTON?*
Answer:	*Typically, we don't have those assets to do that. We rely on our industry partners out there. And there are a lot of vessels in that area just -- for instance, this particular incident kind of sheds a little light on it, and we have -- there are a lot of resources out there. Typically, we are helping each other out. So that is kind of SOP for us."*

3 Discussion

The number of people evacuated from the rig offers a limited insight into the level of success of the evacuation effort. Testimonies have revealed that several of the safety critical systems on Deepwater Horizon failed partly or totally. These systems included BOP, ESD, and the power generators. Several of the crew members did not hear the abandon platform alarm. These are systems that are important safety critical systems that are intended for hazard prevention, control and mitigation. Some of the egress routes were partly blocked.

Explosions, fire and smoke were life-threatening hazards during the EER. One of the important roles of the master of the vessel is to take charge during crisis, and give the order to abandon ship if/when necessary. The master should assess the severity of the situation properly, and if the decision to abandon is made, the master would then give the order to launch the lifeboats and evacuate the installation. Lowering the lifeboats at the right time is critically important for an effective evacuation, because there are a limited number of lifeboats on an installation. If not communicated properly, lifeboats can be launched only partially filled, resulting in personnel being left behind. On the other hand, if members wait too long to launch the lifeboats, they risk being harmed by the explosions, fire and smoke. The Deepwater Horizon had a split chain of command between the OIM and the Captain, this seemed to have caused confusion as the lines of authority and shift of responsibility in the event of an emergency were not understood. Based on available testimonies, it can be questioned if the commands related to executing ESD and abandoning the platform were delayed. The Joint Investigation has spent a considerable amount of time investigation the chain of command.

The following are suggestions for improvement and research needed to improve the EER from offshore installations in the Gulf of Mexico.

3.1 Technical

The free-fall technology with skid launched lifeboats and drop lifeboats is according to Petroleum Safety Authority Norway (PSA) the safest method for ensuring that the means of evacuation moves personnel away from the offshore facility as quickly as possible [16]. This is particularly the case in the North Sea, North Atlantic and Norwegian Sea, where the sea almost never is without swell and waves. The Deepwater Horizon had conventional lifeboats. New production installations in the Norwegian sector are required by law to have free-fall lifeboats. Mobile drilling units in Norway are not required to have free-fall lifeboats, they follow maritime regulations, not petroleum legislation.

There are some companies that claim that evacuation by helicopter is the primary evacuation means. This causes some confusion. Helicopters cannot be used in situations with fire or gas cloud at the platform. Helicopter will also take far longer time on installations that demands several flights due to the restricted capacity on each flight [17]. Helicopter can therefore only be seen as a primary evacuation means in situations where the abandoning is planned in advance, like it was in the case of hurricanes in the Mexico Gulf. Once lifeboats or life rafts have been launched and come clear of the facility, the next issue is rescuing survivors. If a helicopter or rescue vessel is unable to operate under the prevailing conditions, the survivors will have to ride out the weather and wait for an operational window that allows rescue. The time required to ride out a particular condition will depend on the severity of the weather.

It is expected that in some cases, not all members will be able to evacuate using the primary means of evacuation and therefore secondary evacuation means are necessary to ensure the safe evacuation of the personnel left behind or not able to make it to temporary safe refuge (TSR). As seen in the case of Deepwater Horizon there is a need for secondary means of evacuation. These can in addition to life rafts be escape chutes and ladders. Personal survival suits with splash protection extend the available rescue time due to increased protection from waves and hydrocarbons in the sea, in addition to extended time before hypothermia. The survival suites should include emergency beacon to improve chances of locating a survivor.

There are also systems that provide automated real time accounting of personnel during an emergency evacuation. The systems provides a list of personnel on board (POB) or personnel on premise, including key data, trade certificates, cabin number, work area and primary duties during an evacuation or muster drill. At check-in point the muster officer and captain get a real time report of who is expected, who is missing, and who has shown up at the wrong station. In the event that first responders are called in, management can direct them to the work areas or cabin numbers of missing personnel.

3.2 Rescue capacity

The supply ship Damon Bankston played a vital role in rescuing the survivors. Given the remote location of deepwater operations, fast rescue crafts and nearby vessels play a critical role in rescuing personnel from offshore installations in the case of a major accident. Especially is fast response important with a high number of personnel in sea and/or in the case of bad weather. Custom designed third generation rapid response rescue vessels are available. They are specially designed to launch and recover a fast rescue craft or daughter craft from a slipway in the stern. The slipway can also be used to recover a lifeboat from the sea. The sea trials of these vessels are promising and it is generally considered possible to operate in sea conditions up to Hs=< 9m [18].

The USCG did not have the capability to respond as effectively without the presence of the Bankston. The USCG operates HH-65C Dolphin helicopters. These helicopters have a limit on rescue to 3-4 persons.

There is a need for analyze the system for rescue of personnel in sea, life rafts and life boats. The system should include the rig owner, industry partners in area and UCGS. The capability to quickly and efficiently rescue personnel at all times should be analyzed. The Norwegian system for area based emergency preparedness arrangements should be reviewed for relevance [16]. This system includes use of offshore based Search and Rescue (SAR) helicopters as well as fast rescue crafts, in order to provide rescue capabilities within 120 minutes from an emergency.

3.3 Training and skills

Training, knowledge, experience, and competence are important for all EER steps, and in some of the steps it is only human actions that can ensure the proper action, and thereby fulfilling the intended barrier. The crewmembers faced various challenges during their efforts to evacuate the rig. Emergency drills and training have limitations on preparing the crew to deal with real-life emergency situations and unanticipated events. Training and knowledge can though give a basic ability to cope with evacuation scenarios, although the challenges may be different in the real case. The importance of training and skills is recently clearly demonstrated in the Usumacinta accident [3], where all lives lost occurred after the lifeboat and lifesaving capsule had been launched safely.

A unique set of hazards faced those who prepared to jump to sea. Among those hazards was the height from the platform deck to the surface of the water, which they had to jump. Ideally, the crew would have to get as close as possible to the water surface before jumping or entering the sea. Under some circumstances jumping into sea is necessary, and offshore personnel should be trained to do this as safely as possible.

A critical question to be considered is how can it be relied upon that the master of the vessel will be in good enough condition to perform critical tasks in time, such as properly assessing the situation, activating the alarm, and giving the order to muster and abandon ship? This was a problem crewmembers faced following the explosion on board the Piper Alpha. The crew waited on instructions from senior personnel who had the authority to order an evacuation; however they were not aware that the explosion had destroyed the control room killing most of the personnel inside; therefore valuable time was lost waiting for the order to evacuate the installation. In addition did several of the crew wait for helicopters to arrive, not being aware that helicopters cannot approach an installation on fire. During a crisis, it is possible that situations will occur where bypassing the chain of command is unavoidable and necessary; however, the situation must be properly assessed by the individuals such that the result is not detrimental to the safety and success of the operations. This can be accomplished through proper training, and the implementation and practice of worst case scenarios as a part of training and drills.

Human factors play an important role in the completion of emergency procedures. Human factors analysis is rooted in the concept that humans make errors, and the frequency and consequences of these errors are related to human, installation and hazard factors. This can only partly be accounted for in the design of equipment, structures, processes, and procedures. As stress increases, the likelihood of human error also increases. Offshore installations are in harsh environment and incidents can cause extreme stressful situations. The consequences of human error in an offshore emergency can be severe. Clear and extensive knowledge of human behavior when faced with a hazard like fire and explosion is essential for the provision of the appropriate measures for a safe escape from an installation. The EER from the Deepwater Horizon installation show that even though the final result was no casualties, several serious failures occurred in the different sequences, especially related to command and control. This may be due to a mixture of human, installation and hazard features. To determine which measures would reduce the time taken to make decisions, and which steps would lead to people choosing the right escape routes, we need information about the perceptions, intentions and motives of those who are trying to escape from the hazardous situation.

4 Conclusion

The number of survivors from the Deepwater Horizon offers a limited insight into the level of success of the evacuation, escape and rescue (EER) effort. It is our view that the Deepwater Horizon accident did show failures in several of the safety barriers elements that are critical for EER operations, but that all personnel who survived the initial explosions were nevertheless rescued, partly due to fortunate circumstances, including good weather conditions, lifeboats being filled before lowered and the effort of the supply ship Damon Bankston. Testimonies have revealed that several of the safety critical systems on Deepwater Horizon failed partly or totally. These systems included BOP, ESD, alarm system and power generation More research is needed to reveal the reliability and operation of the safety critical systems.

During a crisis, it is possible that situations will occur where bypassing the chain of command is unavoidable and necessary; however, the situation must be properly assessed by the individuals such that the result is not detrimental to the safety and success of the operations. This can be accomplished through proper training, and the implementation and practice of worst case scenarios as a part of training and drills. To determine which measures would reduce the time taken to make decisions, and which steps would lead to people choosing the right escape routes, we need information about the perceptions, intentions and motives of those who are trying to evacuate and escape from the hazardous situation.

There is a need for analyze the system for rescue of personnel in sea, life rafts and life boats. The system should include the rig owner, industry partners in area and UCGS. The capability to quickly and efficiently rescue personnel at all times should be analyzed. The Norwegian system for area based emergency preparedness cooperation may be used as a model.

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